HIGHWAY RESEARCH REPORT

A COMPARISON OF
THE CHLOE PROFILOMETER
AND
THE CA   ⊃GRAPH

67-12

Research Report
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Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

A COMPARISON OF
THE CHLOE PROFILOMETER
AND
THE CALIFORNIA PROFILOGRAPH

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Very truly yours,

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ABSTRACT: A profilometer known as the "CHLOE Profilometer",
               developed by the Road Test Staff of the AASHO Road
               Test at Ottawa, Illinois, was used in a study to
               determine whether the AASHO serviceability rating
               method is adaptable and desirable for California
               pavements, and if profiles obtained with the
               California Profilograph could be incorporated into
               the serviceability index formula.

               The study consisted of obtaining longitudinal
               profile data, using both the CHLOE Profilometer and
               the California Profilograph. Ten sections of pave-
               ment were involved, including both asphaltic and
               portland cement concrete varying in condition from
               excellent to poor. Also included was some data
               from an asphalt concrete test road built as a
               cooperative test project by San Diego County and
               the Asphalt Institute. Statistical methods were
               used to evaluate the data. Electronic modifica-
               tions were made to both systems to facilitate the
               accumulation of data.

ACKNOWLEDGMENT

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The opinions, findings, and conclusions expressed in this report are those of the authors and are not necessarily those held by the Bureau of Public Roads.

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I. INTRODUCTION AND BACKGROUND MATERIAL

During the AASHO Road Test at Ottawa, Illinois (1956-1961), pavements were evaluated by a method designated as "The Serviceability Performance System."[1] This system is described as a method wherein the serviceability of pavements was rated subjectively by a panel made up of men selected to represent important groups of highway users. Through multiple regression analysis, a mathematical index was derived and validated through which pavement ratings were satisfactorily estimated from objective measurements taken on the pavements. These serviceability indices always refer to the conditions existing at the time the measurements (or ratings) are made. Performance of a pavement may then be determined by summarizing the serviceability record over a period of time.

This system is considered by some to have potential for wide application in the highway field, particularly in sufficiency rating, evaluation of design systems, and evaluation of paving materials and construction techniques through the provision of an objective means for evaluation of performance.

Early in the deliberations concerning the AASHO Road Test, it was decided to attempt development of a new method to measure pavement roughness. The outcome was the development of a quite elaborate and expensive device which was designated as the Road Test Profilometer. This instrument was designed to provide continuous analog records, from both wheel paths, of the slope of the pavement as the device moved along the pavement. From these records, three profiles could be developed; namely, displacement profile, slope profile, and acceleration profile. Eventually it was decided to use only the slope profile. From this slope profile "Slope Variance", which is defined as the variance (mean square deviation) of a set of slopes about the mean slope, could be derived, and was chosen as the measure of pavement roughness for use as an element of serviceability. Other elements of serviceability includes summarizations of rut depth in the wheel paths, and cracking and patching of the surfacing material.

When it had been determined that "Slope Variance" by itself was to be the statistic used as a measure of pavement roughness, it was clear that the Road Test Profilometer, with its expensive electronic chart reader and digital computer, was far too sophisticated for the job at hand. Consequently, although this instrument was highly useful for the special purpose of a large highway research project, it would not be appropriate for routine highway evaluation.

With this in mind, W. N. Carey, Jr., Engineer for Research, H. C. Huckins, Instrumentation Supervisor, R. C. Leathers, Engineer of Special Assignments, and other engineers of the AASHO Road Test Staff, developed a much simpler device for the purpose, designated as the CHLOE Profilometer.[2] An arrangement of the initials of the surnames listed above plus those of "other engineers" spells "CHLOE", hence the name.

The CHLOE Profilometer is a relatively simple, electronic-mechanical device. It is towed by a vehicle over any section of pavement. Three statistics, the number of sample points (slope is sampled at 6-inch intervals along the wheel path), the sum of the actual slope numbers, and the sum of the squared slope numbers are accumulated and displayed on the panel of an electronic device that is in the towing vehicle. These three statistics can then be combined mathematically to determine the summary statistic, Slope Variance.

In July 1962, the Bureau of Public Roads instigated a program whereby individual states could procure CHLOE Profilometers with Bureau HPR Funds. The California Division of Highways purchased a CHLOE Profilometer for the purpose of determining if the CHLOE equipment was adaptable and desirable for use on California pavements, and whether profiles made with the California Profilograph could be correlated with CHLOE data and incorporated into a serviceability index formula.

II. CONCLUSIONS

Good correlation does not exist between Slope Variance and Profile Index throughout a broad spectrum of road characteristics. Slope Variance and Profile Index represent methods of analysis which place emphasis on different roadway characteristics.

Slope Variance can be readily obtained with the California Profilograph by the simple addition of an analog magnetic tape recorder. Additionally, the California Profilograph can be used for other parameters of interest, such as transverse Slope Variations and the degree of faulting and/or curling. The addition of the analog magnetic tape recorder would further expand the capability of the profilograph to include derivation of any other indexes which are simply the result of a different method of analyzing the longitudinal profile.

The CHLOE system in its present state of design is inadequate from a functional reliability aspect. At present no adequate method of assuring the validity of data is incorporated in the system.

While both the CHLOE Profilometer and the California Profilograph can be considered as satisfactory instruments to provide longitudinal profile data of pavements, they both have the disadvantage of operating at very slow speeds (2 to 4 mph). To perform condition surveys safely under traffic, equipment that will operate at speeds of 40 mph or greater is believed to be a practical necessity.

III. SELECTION OF TEST SECTIONS

The selection of test sections was made to include projects that would provide a good cross-section of varying surface conditions, such as curling, faulting, undulating, smooth, and rough. Both asphalt concrete and portland cement concrete were included in the selection. The projects chosen ranged in condition from excellent to poor. The following ten listed projects from the California highway system were selected for this study.

Location	Type Const.	Year Const.	Length, Miles	Condition
Frontage Rd. in Yolo Co. para-lelling IS 80 from Yolo Cause-way to 1.7 mi.W.	2-lane PCC	1932	1.7	EB lane faulted, otherwise in fair condition. Fair to good riding quality
Hwy 99 between Salida and Ripon	4-lane PCC divided	1946	4.5	Badly faulted. Poor riding quality
Hwy 50 betw. Lodi and Stockton	4-lane divided AC	1964	6.6	Excellent condition. Excellent rid-ing quality
Hwy 50 between Camino and Sly Park Road	4-lane divided AC	1965	6.6	Excellent con-dition. Poor to good riding quality
IS 505 in Solano Co. betw. IS 80 and 5.7 mi. N.	2-lane PCC	1946	5.7	Good condition. Good riding quality
IS 505 in Solano Co. betw. Sweeny Cr. & Putah Cr.	2-lane	1960	5.2	Fair to good condition. Fair riding quality
Hwy 50 betw. Citrus Rd. and Alder Cr.	4-lane divided PCC	1962	2.0	Excellent con-dition. Good riding quality

Location	Type Const.	Year Const.	Length, Miles	Condition
Hwy 50 between Folsom Jct. & 2.2 mi.E. of El Dorado Co. line	4-lane divided AC	1965	8.4	Excellent condition. Excellent riding quality
State Rt. 152 Merced and Santa Clara Co. Partial rerouting of Pacheco Pass	4-lane divided PCC	1965	12.5	Curling developed. Fair to good riding condition
IS 80 in Solano Co. between Woodland Wye & SPRR underpass W. of Davis	4-lane divided PCC	1941	4.6	Poor condition. Badly cracked and faulted. Poor riding quality

In addition to the California highway projects, data from a cooperative experimental project involving San Diego County and The Asphalt Institute is included. Testing pertaining to serviceability was done by California Division of Highways personnel. Due to the nature of the project, the data obtained was treated as a separate entity and analyzed independently.

IV. TESTING

1. Scope

The prime consideration was to determine the extent of correlation between Profile Index as obtained by the California Profilograph and Slope Variance as obtained by the CHLOE Profilometer. The California profile index and slope variance are derived solely from the longitudinal profile, while the Present Serviceability Index includes other elements of serviceability, such as rut depth, and cracking and patching of the surface material. For the purpose of making the various correlation analyses, it was decided to eliminate evaluation of these miscellaneous elements of the Present Serviceability Index system.

Lengths of test sections for the 10 California highway system projects were limited to 1000 + feet, and the number varied from two to eight depending on the size of the project. All measurements were taken in the outer wheel path, and most were taken in duplicate or triplicate to insure accuracy, and to provide data to measure the repeatability of each system.

The San Diego County-Asphalt Institute project consisted of 35 test sections constructed with a uniform thickness of asphalt concrete surfacing with each section having variables in thickness and type of base materials. Each section was approximately 200 feet in length and was separated by transition areas ranging in length from 50 feet to 340 feet. The complete sections were measured. The project has been opened to traffic for only a few days when tested. Structurally, the road was in good condition; however, the riding quality was judged poor.

During the initial testing of the CHLOE equipment, numerous mechanical and electronic problems were encountered. Although many of the computer readings were readily detected as erroneous due to equipment malfunction, some erroneous readings were not so obvious. Malfunctions which resulted in negative or extremely high Slope Variances were easily recognized, but a malfunction causing a Slope Variance error of 10% to 20% cannot readily be differentiated from a valid Slope Variance determination. It became apparent that some independent means of checking proper operation of the CHLOE equipment was needed.

One of the disadvantages of the CHLOE system is that only totalized figures are recorded and limited information

is available with which to assure the validity of results or to ascertain the cause of erroneous readings. It was, therefore, decided to utilize existing laboratory equipment to provide a parallel electronic system capable of recording individual slope readings on a magnetic tape. This will be referred to as the "Supplemental CHLOE" system. (See Figure 1.) A computer program was written to calculate the slope variance as well as to provide a print-out of all individual slope readings.
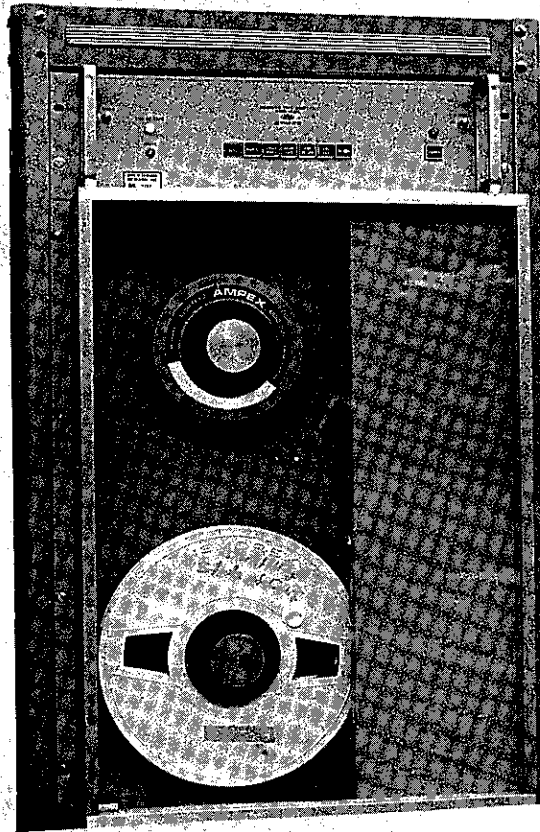

Fig. 1 - Cook magnetic tape recorder and coupler

The California Profilograph[3,4] measures and records on a strip chart, a profile measured from a moving 25-foot long reference line. The Profile Index is derived from the strip chart by overlaying the profile line with a special rule and counting and weighting deviations above and below a 0.2-inch blanking band. Profile Index is determined as "inches per mile."

The CHLOE Profilometer measures slope every 6 inches of pavement by means of a slope transducer, and records slopes over a numerical range of from 1 to 29, with each increment representing a 10-minute arc. This measurement is taken using a 9-inch baseline and is referred to a 21-foot reference line. The slope readings are mathematically combined and the statistic, "Slope Variance" is calculated.

To correlate CHLOE Slope Variance and Profile Index poses the problem of comparing two systems differing both in measurement principle and in method of analysis. Any lack of correlation would leave the problem of whether the difference existed in the method of analysis or in measurement principle.

In order to better understand the comparison between the two systems, it was decided that an analog magnetic tape recorder would be incorporated into the existing California Profilograph's recording system. A "profile", identical to that recorded on the strip chart, would be recorded on the magnetic tape. (Figure 2.) The tape recording would then be played back into the digital magnetic tape system so as to simulate running a CHLOE Profilometer over the profile recorded by the California Profilograph. That is, slope readings would be taken every 6 inches using a 9-inch baseline. This will be referred to as "California Profilograph Slope Variance." The digitized profilograph recording required that a second computer program be written. Block diagrams, computer programs, and general descriptions of these systems will be found in Appendix I.

With the aid of the aforementioned systems, it was possible to compare measurement techniques as well as methods of analysis. By taking repeat runs on all measured sections, repeatability of the measuring systems could be determined. All test sections were run with the California Profilograph towing the CHLOE Profilometer (Figures 3 and 4).

Extensive loss of data was experience due to mechanical and electronic malfunctions in the CHLOE Profilometer

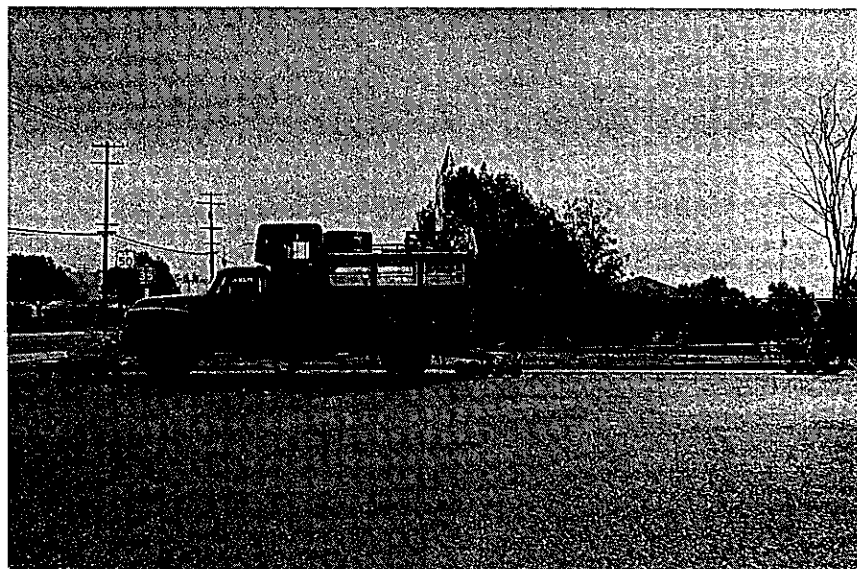Fig. 2 - Pemco analog magnetic tape recorder and
power supply

Fig. 3 - California Profilograph and CHLOE Profilo-
meter hooked in tandem

Fig. 4 - Rear view of testing hook-up with follow
car

equipment. It is believed that additional reliability could
be designed into this equipment and the problem could be
minimized. Some degree of improvement in reliability was
provided by substituting hard rubber-tired sensing wheels
for the nylon wheels that were originally supplied with the
equipment. By making this change, a reduction of vibration
in the area of the slope transducer was accomplished. This
lowered the sample impulse loss that was being caused by the
roller contact bouncing off of the printed circuit switch
plate. The supplemental CHLOE system also accounted for the
loss of some data due both to equipment malfunctions, and
computer program problems. The California Profilograph Slope
Variance system worked very well although there was some
signal degradation due to a poor signal to noise ratio in
the recording amplifiers. This resulted in a slightly
degraded repeatability in the results from that system. A
better tape recorder and sensor could have corrected this
problem. The California Profilograph equipment performed
very well throughout the testing period.

V. ANALYSIS

Standard methods of linear regression analysis were used for the correlations.

It was apparent that the most reliable readings were obtained with the supplemental CHLOE system, consequently this system was used as a basis for all comparisons.

Early experience with the CHLOE equipment indicated that there was no means of being assured of obtaining valid readings. Comparison between the CHLOE system and the supplemental CHLOE system proved this to be true. However, when the obviously erroneous CHLOE readings were eliminated, the correlation was excellent (see Figure 5). The reliability of the CHLOE system was such that this study could not have been completed without the supplemental magnetic tape (supplemental CHLOE) system. Every effort was made short of complete redesign to get the CHLOE system to function properly before the supplemental system was incorporated. The magnetic tape system did not prove to be completely trouble-free. These difficulties were of a minor nature and were easily remedied.

A regression analysis made on the combined data from the ten road projects used in the study indicates a general correlation exists between "Slope Variance" and "Profile Index". (See Figure 6.) However, the wide range of scatter of the plotted data suggested that it would be advisable to make some separate analysis of the various road types.

When separate analyses were made, it became apparent that the slope of the determined regression lines varied considerably with the pavement characteristics. The type of surface irregularity and its wave length was the determining factor in establishing the slope of the regression line. Profile Index increased more rapidly than Slope Variance when there was a predominance of longer wave length irregularities. Conversely, Slope Variances increased more rapidly than Profile Index when the roadway contained more of the shorter wave length irregularities.

This is exemplified by Figures 7 through 12. For example, Figure 7 represents the regression analysis of a fair riding portland cement concrete pavement with long wave length characteristics. These long wave length irregularities contribute greatly to the "Profile Index", but have considerably less influence on the "Slope Variance." This

characteristic is graphically depicted in Figure 12a which represents a typical section of profile obtained with the California Profilograph from this road. The long undulating irregularities in this case extend considerably above and below the 0.2-inch blanking band of the profile evaluating rule to provide a high Profile Index. On the other hand, these irregularities due to their length and shape, contribute relatively little to the amount of Slope Variance.

On the other extreme, Figure 8 represents the regression analysis of a rough riding portland cement concrete pavement predominant in short wave length irregularities caused by faulting at the joints and by intermittent cracking. In this case, much of the roughness or short wave length irregularities are eliminated by the 0.2-inch blanking band when the Profile Index is determined. This characteristic is graphically depicted by Figure 12b which represents a typical section of profile obtained with the California Profilograph from this road.

Another type of road characteristic is represented by the regression analysis shown on Figure 9. This is a fair riding portland cement concrete pavement that is exhibiting some degree of slab curling and contains both short and long wave length irregularities. A graphic representation of this characteristic is shown in Figure 12c.

Figures 10 and 11 represent regression analyses on asphalt concrete roads with varying characteristics. Figure 10 represents a composite analysis of three relatively smooth roads containing both short and long wave length irregularities. Figure 11 represents a very rough road with predominantly long wave length irregularities.

The analyses indicate that although there is general correlation between Slope Variance and Profile Index, it is evident that certain types of pavement characteristics can influence one differently than the other. Determination of Slope Variance from Profile Index (or vice-versa) to a reasonable degree of accuracy would not be possible due to the fact that the two methods of analysis place emphasis on different roadway characteristics.

To compare measurement technique, correlations were made between the CHLOE Slope Variance and California Profilograph Slope Variance. (See Figure 13.) This correlation was very good and indicates that the physical measurement systems react very nearly the same. Therefore, it is concluded that the inconsistencies in the Profile

Index-Slope Variance regression equations are attributable to differences in the methods of analysis.

Repeatability was determined by obtaining the standard deviation among replications by the "Average Range Method".[5] While this method gives only a rough estimate of the standard deviation, it was considered adequate for the purpose. The comparison of replications indicated standard deviations of 1.0 or lower for the Profile Index-Slope Variation obtained with the CHLOE equipment, and Slope Variance obtained by the supplemental CHLOE system. The Slope Variance obtained from the California Profilograph showed a standard deviation of 2.0. When the shorter sections from the San Diego County-Asphalt Institute project (200 feet) were involved, the standard deviation of the Profile Index replications degraded from 1.0 to a value of 2.0.

Figure 5

SLOPE VARIANCE (CHLOE)
VS.
SLOPE VARIANCE (SUPPLEMENTAL CHLOE SYSTEM)

COEFFICIENT OF CORRELATION = 0.998
STANDARD ERROR OF ESTIMATE = 0.603
$Y = 0.132 + 0.997X$

SLOPE VARIANCE (CHLOE)

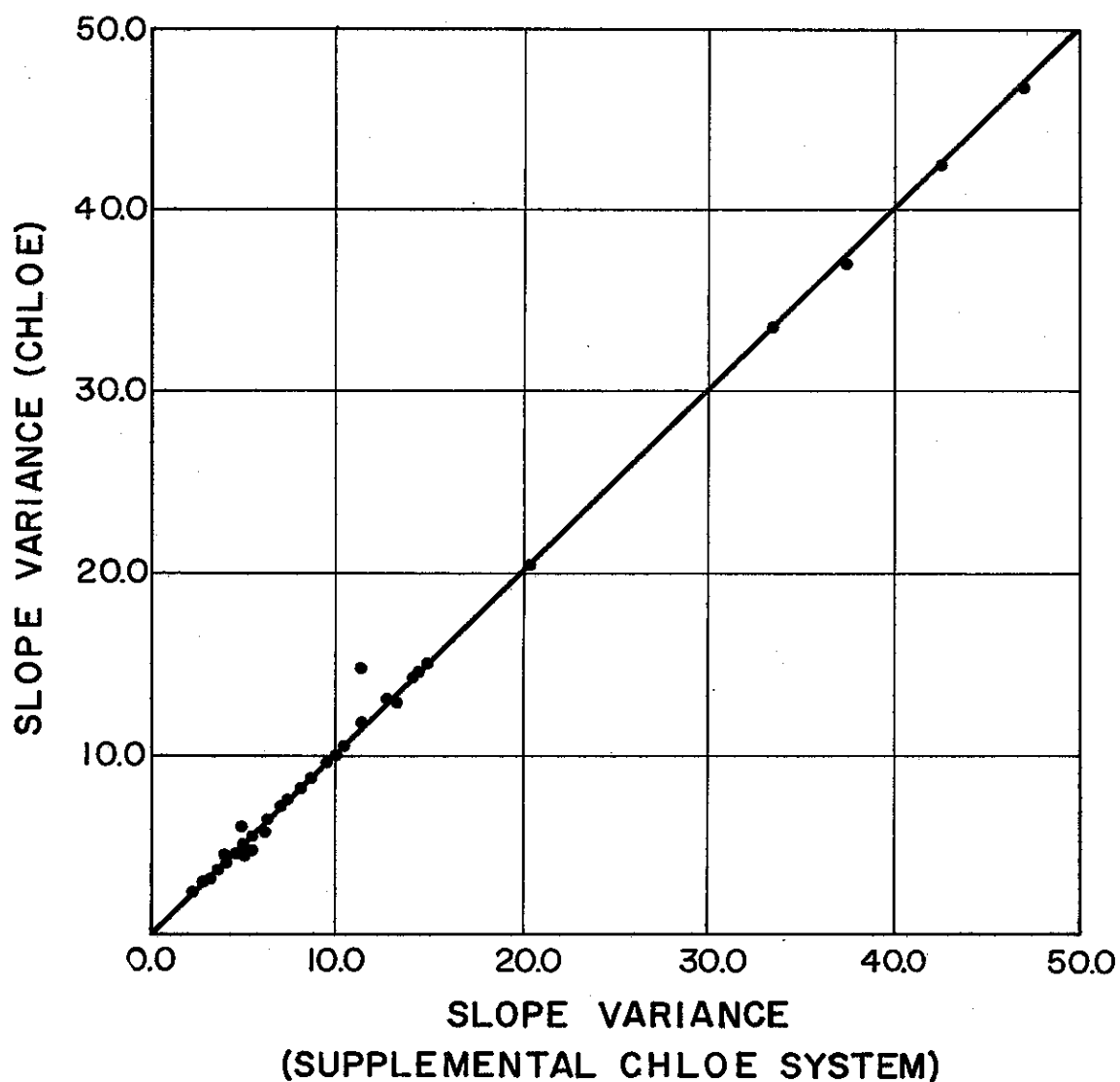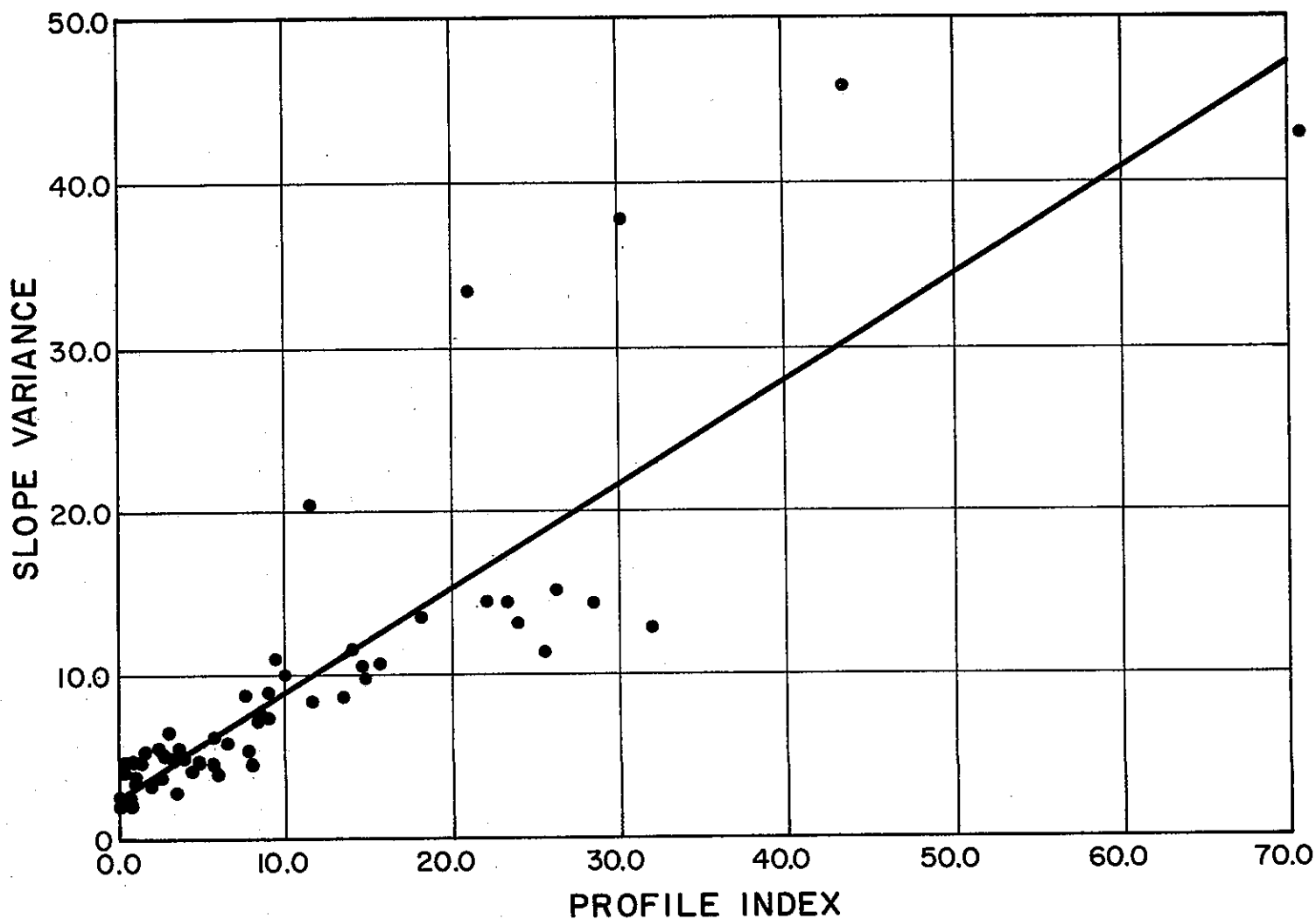SLOPE VARIANCE
(SUPPLEMENTAL CHLOE SYSTEM)

Figure 6

SLOPE VARIANCE VS PROFILE INDEX

10 TEST SECTIONS COMBINED

COEFF. OF CORR.= 0.859
STD. ERROR OF EST.=4.85
$Y=2.7014 + 0.638X$

SLOPE VARIANCE VS PROFILE INDEX

Figure 7

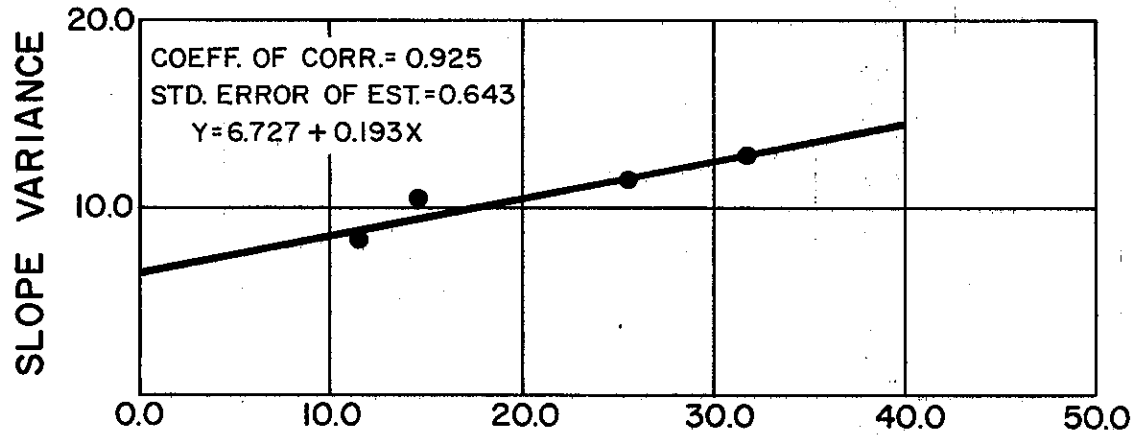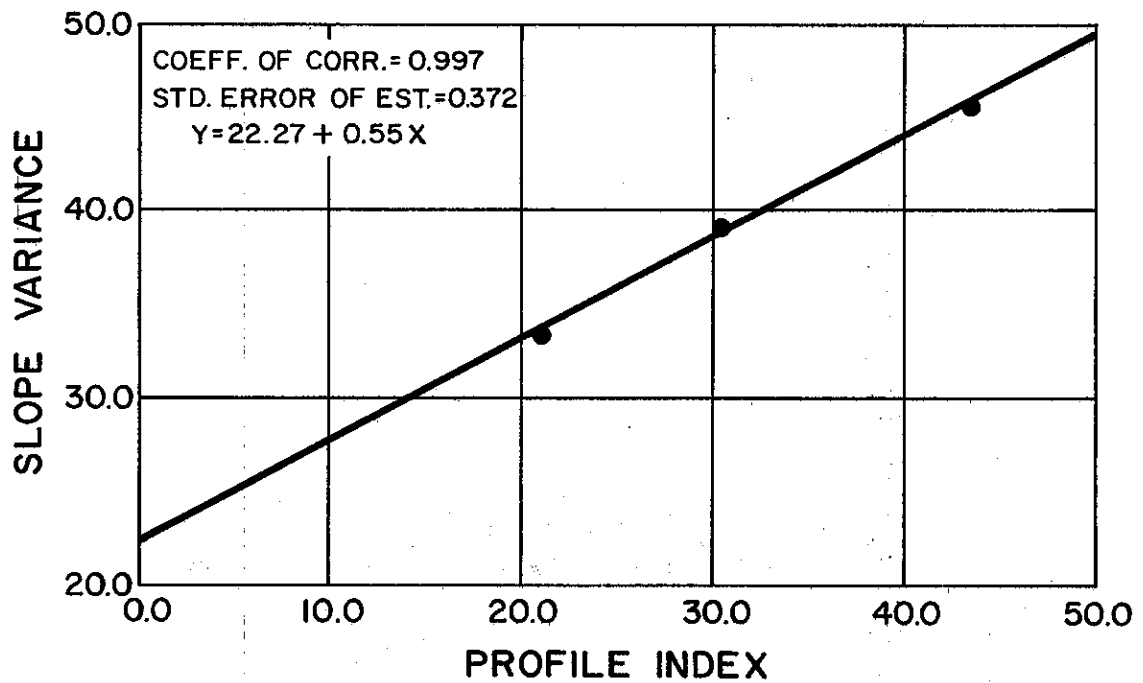## INTERSTATE 505 IN SOLANO CO. BETWEEN SWEENY CREEK AND PUTAH CREEK

COEFF. OF CORR.= 0.925
STD. ERROR OF EST.=0.643
$Y = 6.727 + 0.193X$

Figure 8

STATE SIGN RTE. 99 BETWEEN SALIDA AND RIPON

COEFF. OF CORR.= 0.997
STD. ERROR OF EST.=0.372
$Y = 22.27 + 0.55X$

PROFILE INDEX

SLOPE VARIANCE VS PROFILE INDEX

Figure 9
STATE ROUTE 152 PACHECO PASS RELOCATION

COEFF. OF CORR.=0.834
STD. ERROR OF EST.=1.059
Y=6.2046+0.334X
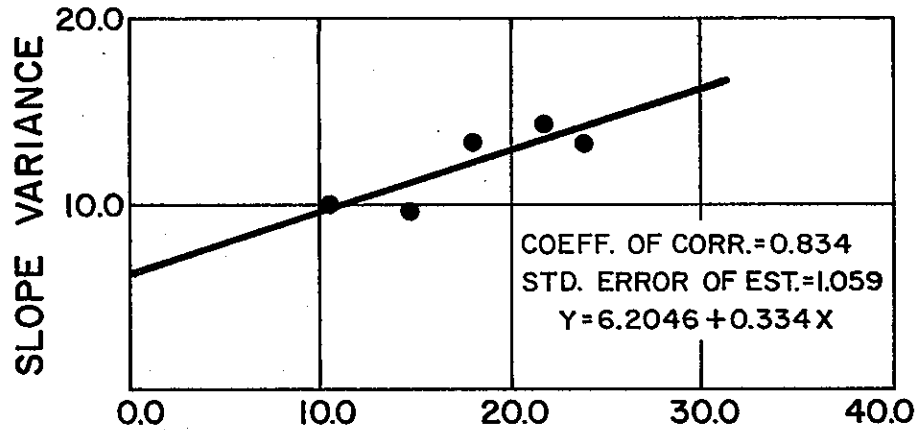
Figure 10
COMBINED ASPHALT CONCRETE PROJECTS

COEFF. OF CORR.= 0.886
STD. ERROR OF EST.=0.896
Y=3.177+0.468X
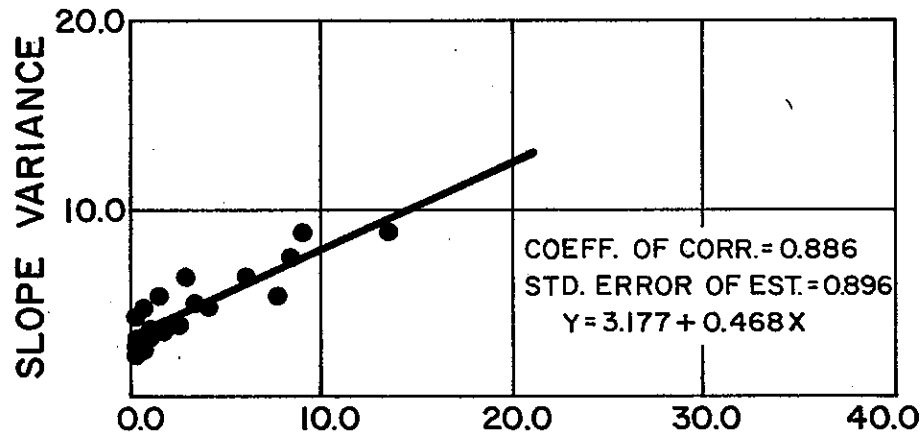
Figure 11
SAN DIEGO CO. AND ASPHALT INSTITUTE AUGUST 1966

COEFF. OF CORR.=0.550
STD. ERROR OF EST.=2.299
Y=6.466+0.217X
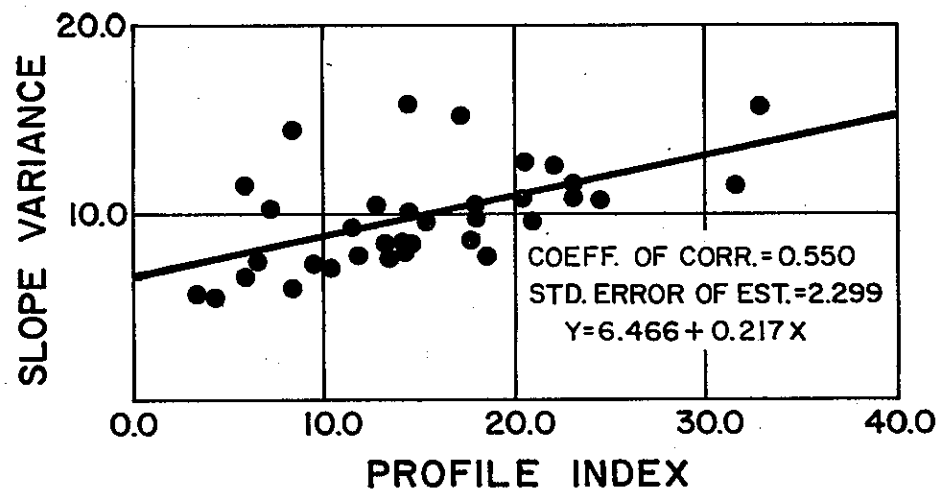
PROFILE INDEX

Figure 12

12a
PROFILE INDEX = 34.0
SLOPE VARIANCE = 13.0

12 b
PROFILE INDEX = 35.0
SLOPE VARIANCE = 41.5

Scale
Longt. 1" = 25'
Vert. 1" = 1"

12 c
PROFILE INDEX = 16.0
SLOPE VARIANCE = 14.0

Figure 13

SLOPE VARIANCE
(SUPPLEMENTAL CHLOE SYSTEM)
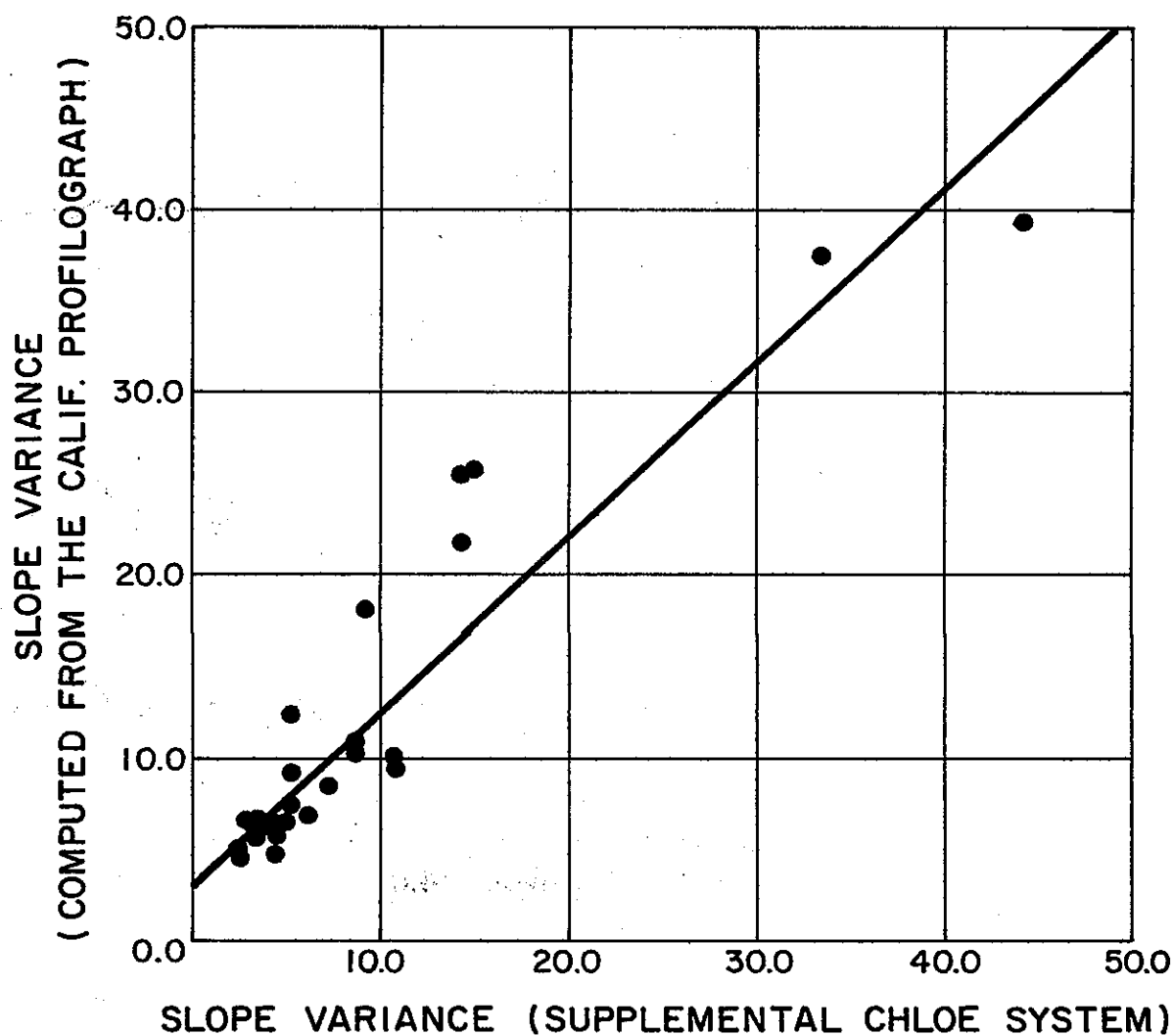
VS.

SLOPE VARIANCE
(COMPUTED FROM THE CALIF. PROFILOGRAPH)

COEFFICIENT OF CORRELATION = 0.939
STANDARD ERROR OF ESTIMATE = 3.405
Y = 3.233 + 0.951 X

SLOPE VARIANCE (SUPPLEMENTAL CHLOE SYSTEM)

VI. DISCUSSION

California's primary use for a profilometer is for construction control purposes. The profilometer used for this purpose is basically a lightweight moving straightedge having a 25-foot wheel base. The instrument is designed to produce a continuous line on a strip chart depicting the changes in the height of its center wheel with respect to the average height of the front and rear wheels.

A truck-mounted profilometer was developed for use on roads under traffic. This equipment (used in this project) electronically produces a longitudinal profile on a strip chart by the same moving straightedge principle.

The profile obtained by this method is evaluated and assigned an index number which is referred to as the "Profile Index", and is expressed in inches per mile. This index is an excellent measure of the smoothness of newly constructed pavements, but on older highways, the results are not necessarily a satisfactory measure of riding quality. For instance, it is possible to have a pavement with a high Profile Index ride more smoothly than one with a lower index. By studying the strip chart, it is possible to better evaluate the profile. For example, faulting and curling of portland cement concrete pavement slabs is clearly defined, as well as the undulating type of irregularities associated with asphaltic concrete pavement. Cracks and patches are also recorded manually on the strip chart by use of an event marker. Cross slope deviations can also be continually recorded on the chart by means of an electronic pendulum to pen hook-up. With this amount of data, it is possible to produce an adequate condition survey. In addition to these data acquisition facilities, it would be relatively simple to permanently add a transducer and record data with an analog magnetic tape recorder. The data could be computer reduced to Slope Variance or any other longitudinal profile-dependent variable.

With either the CHLOE or the truck-mounted profilometer, there exists the disadvantage of extremely low operating speeds (2 to 5 mph) which makes data acquisition for condition survey extremely hazardous with present-day traffic. The need for a device to obtain longitudinal profile data under traffic at relatively high speeds has long been recognized. In 1964, the Research Laboratories of General Motors Corporation completed development of a device for this purpose designated as the GMR Road Profilometer.[6] This equipment is operated at speeds of 40 to 50 mph. By use of electronic data processing equipment, the information obtained by the profilometer may be

transformed into any of the common forms of longitudinal
profile evaluation, such as Profile Index, Slope Variance,
Roughness Index, etc. With the advent of this relatively
high speed equipment, both the California Profilograph and
the CHLOE Profilometer appear to be outmoded with respect
to obtaining this type of data under traffic. Although the
cost of the GMR Road Profilometer is considerably more than
either the CHLOE or the California Profilograph, the slow
operating speed of the latter two makes the process of
obtaining road condition data under traffic so hazardous as
to outweigh monetary consideration. The cost per mile of
rating a pavement with high speed equipment would be con-
siderably lower than either the California Profilograph or
the CHLOE equipment, thereby making the overall operation
more comparable in cost.

As of this writing, little experience is available
with respect to the adaptability of the GMR data to pavement
evaluation formulas. Correlation studies would have to be
made to gather more information in this area. From data
available to date, it is evident that high speed operation
will be reflected in the trace and specific pavement features
such as faulting and curling cannot be readily identified to
the degree shown on the California Profilograph traces.

The CHLOE equipment in its present form does not lend
itself to construction control of portland cement concrete
pavement. Its excessive weight prohibits the equipment from
running on one day old concrete, and the CHLOE Profilometer
does not indicate the exact location of excessive roughness
for remedial grinding as does the California Profilograph.

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APPENDIX

I. GENERAL TESTING SYSTEM

1. California Profilograph

The California truck-mounted profilograph is an electronic moving straightedge device. It consists basically of elevation sensing units and a strip chart recorder. The elevation sensing units are linear variable differential transformers (LVDT) mounted on arm and wheel assemblies which are pivoted on the truck frame. There are three such elevation sensing units for each wheel track. The front and rear sensing units are activated from points 25 feet apart, and the third unit is located at the midpoint. The three LVDT's are series connected such that the total output signal of the three LVDT's is equal to the algebraic sum of the individual LVDT's. For a given movement, the output signal of the midpoint sensing unit has twice the amplitude and the opposite polarity as the output signals of the front or rear sensing units. Since the total output of the three LVDT's equals the algebraic sum of the individual LVDT's, the output signal is proportional to the elevation at the midpoint sensing unit as measured from a reference line established by the front and rear sensing units. The output signal of this sensing system is series connected with a follower LVDT located in the recorder to form a null balance circuit. The follower LVDT is mechanically coupled to a servo motor which is driven by an amplified signal from the null balance circuit. When the follower LVDT moves to a point such that its voltage output is equal and opposite to that of the sum of the sensing LVDT's, null balance has been obtained. The input to the amplifier is nominally zero volts, hence the servo motor stops. The action of the servo motor in balancing the circuit also moves the respective pen drive, thus producing and recording the vertical deviations of the pavement from the reference line at a one-to-one ratio.
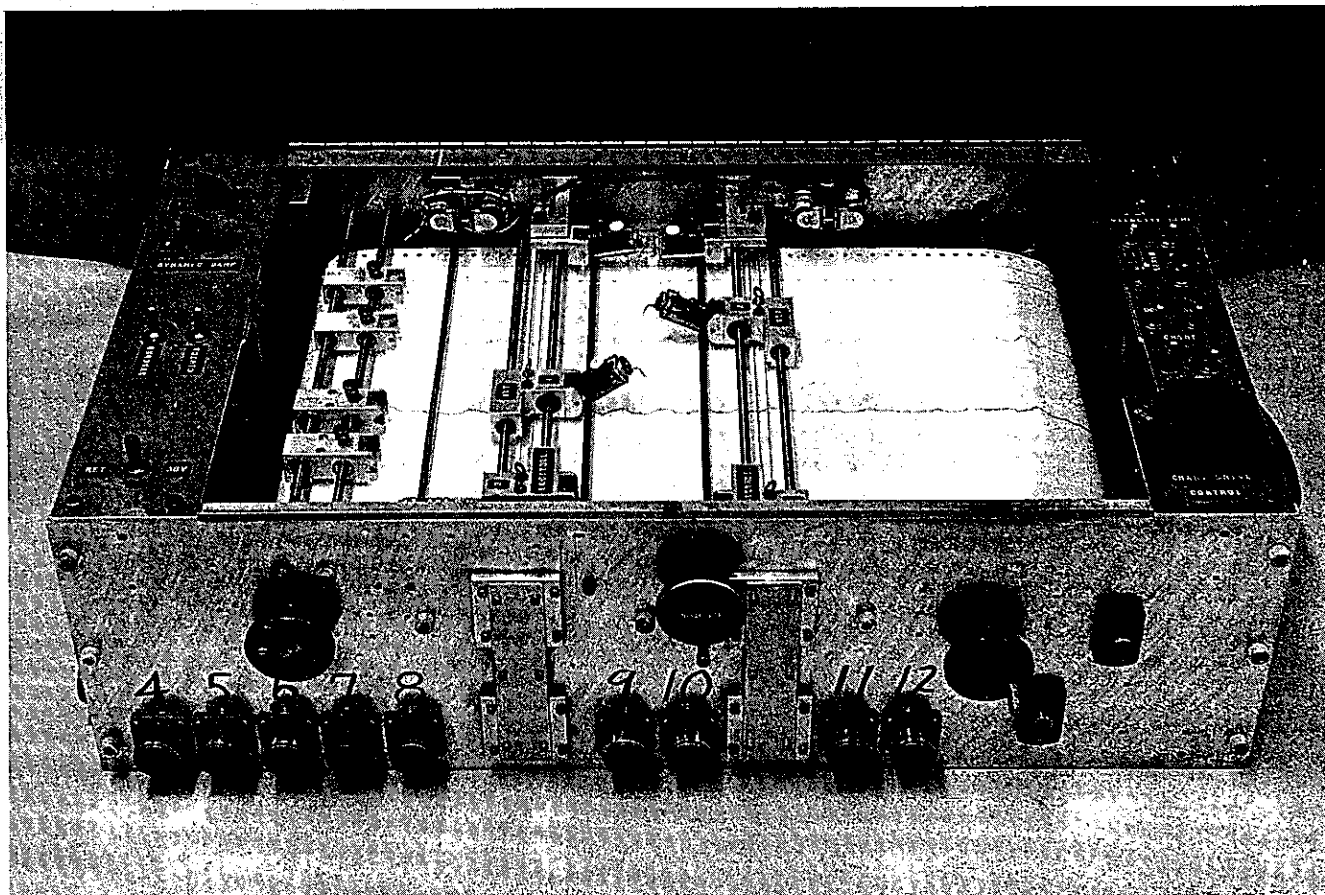
Figure 14 - Recorder for the California Profilograph

2.   CHLOE Profilometer

The CHLOE Profilometer consists of two units. The
trailer unit carries the transducing mechanism. The
electronic computer located in the towing vehicle accepts
information from the transducer, performs a computation
on it, and indicates the results.
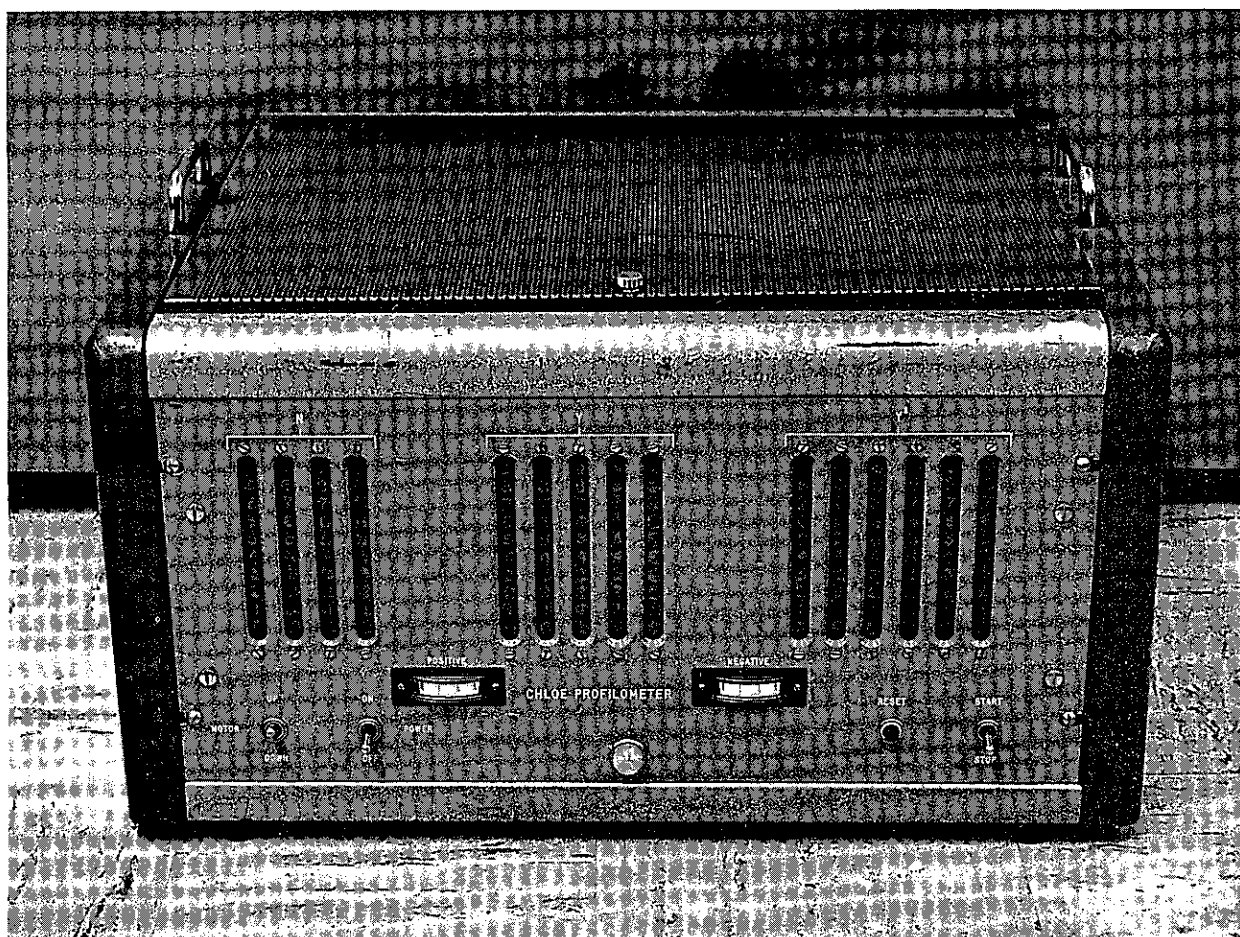
Figure 15 - CHLOE Computer

The slope transducer is carried at the rear of
a trailer with a 20-foot boom. It is comprised of two
8-inch wheels mounted in tandem on 9-inch centers. A
roller contact mounted on an upright arm fastened at
the pivot point between the wheels contacts a printed
circuit switch with 29 active segments (each segment
represents a 10-minute arc). The transducer provides
an incremental measure of angle between the bar
connecting the two slope wheels and the arbitrary
reference of the trailer unit.

A slotted disc-photocell combination attached to one of the carriage wheels produces pulses at 3-inch intervals of highway travel. These pulses are used to generate one "command to sample" pulse for every 6 inches of travel.

3. Supplemental CHLOE System

A logic interface board consisting of emitter followers (in order not to overload the CHLOE computer circuitry) was connected to the CHLOE computer storage output which receives the same coded decimal information as received by the CHLOE computer. A diode matrix on the interface board converted the information into binary coded decimal form (BCD) for entry into Dymec #2546 magnetic tape coupler. The magnetic tape coupler converted the parallel BCD format into a serial output IBM 7 channel NRZ format for recording a Cook 150 incremental magnetic tape recorder. The information from the incremental tape recorder was used to verify the totalized computed information obtained from the CHLOE computer.

4. California Profilograph
Slope Variance System

A rotary potentiometer excited by a DC battery was mechanically linked to the California Profilograph strip chart recorder. This potentiometer produced a continuous signal which was recorded on the first channel of a Pemco analog tape recorder.

An emitter follower triggering circuit was connected to the disc-photocell output. The triggering circuit output (pulses at intervals representing 3 inches of travelled pavement) was recorded on the second channel of the Pemco analog tape recorder.

When the Pemco tape recording was played back, the recorded continuous information signal from the first channel was attenuated through a calibration potentiometer. The signal was then fed into a Krohn-Hite #335 variable filter to eliminate the extraneous noise signals. From the output of the Krohn-Hite variable filter, the signal went through a DC offset circuit to change the reference voltage to a desired value. When commanded by the triggering voltage from the recorded pulses on the second channel of the Pemco tape recorder, the signal was sampled for ten milliseconds by a Dymec #241A integrating digital voltmeter. The digital voltmeter converted the measured signal level to two

characters of binary coded decimal information which were then recorded on the digital tape recorder. The magnetic tape so recorded was directly computer processed.

Since each of the 29 active segments of the CHLOE trailer section represents a 10 minute arc, it was calculated that 0.0262-inch deflection on the California Profilograph strip chart recorder represents a change of one segment on the CHLOE; therefore, one inch deflection on the chart recorder will equal 38 segments.

During the recording, a 1-inch deflection was placed on the Profilograph strip recorder and recorded on the Pemco analog tape recorder for calibration purposes. During digitizing of the Pemco analog tape information using the calibration potentiometer, the 1-inch deflection was equated to read 0.38-volt on the Dymec #2401A digital voltmeter so that a voltage signal of 0.01-volt represented the same value as one active segment.

II. COMPUTER PROGRAM DESCRIPTION

A computer program was written to handle the data from the supplemental recording system. Data was recorded on the Cook 150 digital incremental recorder in BCD form. Recording density was 200 B.P.I. Approximately 2000 two-digit numbers constituted a file. This represents approximately 1000 feet of pavement.

The program utilized IBM 704 and IBM 1401 computers. The following information was contained in the printed output from the computer:

1. Each individual two-digit number (y)
2. The number of two-digit numbers (n)
3. The sum of the numbers (Σy)
4. The sum of the squares of the numbers (Σy^2)
5. The average of the numbers $\left(\dfrac{\Sigma y}{n}\right)$
6. The slope variance (SV) which is defined as follows:

$$SV = 8.46 \left[\frac{\Sigma y^2}{n} - \left(\frac{\Sigma y}{n}\right)^2 \right]$$

Figure 16

DIGITIZING SYSTEM

Block Diagram

```
┌──────────────┐     ┌──────────────┐  #2  ┌──────────────┐     ┌──────────────┐
│   Pemco      │     │   Pemco      │─────▶│  Triggering  │────▶│    Dymec     │
│Power Supply  │─────│   Analog     │      │   Circuit    │     │ Integrating  │
│              │     │Tape Recorder │      │              │     │   Digital    │
└──────────────┘     └──────────────┘      └──────────────┘     │  Voltmeter   │
                            │ #1                                 └──────────────┘
                            ▼                                           │
┌──────────────┐     ┌──────────────┐     ┌──────────────┐            │
│ Calibration  │     │  Krohn-Hite  │     │  D.C.Offset  │            │
│Potentiometer │────▶│   Variable   │────▶│Potentiometer │            │
│              │     │   Filter     │     │              │            │
└──────────────┘     └──────────────┘     └──────────────┘            │
                                                                       ▼
              ┌──────────────┐            ┌──────────────┐
              │   Cook150    │            │    Dymec     │
              │ Incremental  │◀───────────│   Magnetic   │
              │   Magnetic   │            │ Tape Coupler │
              │Tape Recorder │            │              │
              └──────────────┘            └──────────────┘
```
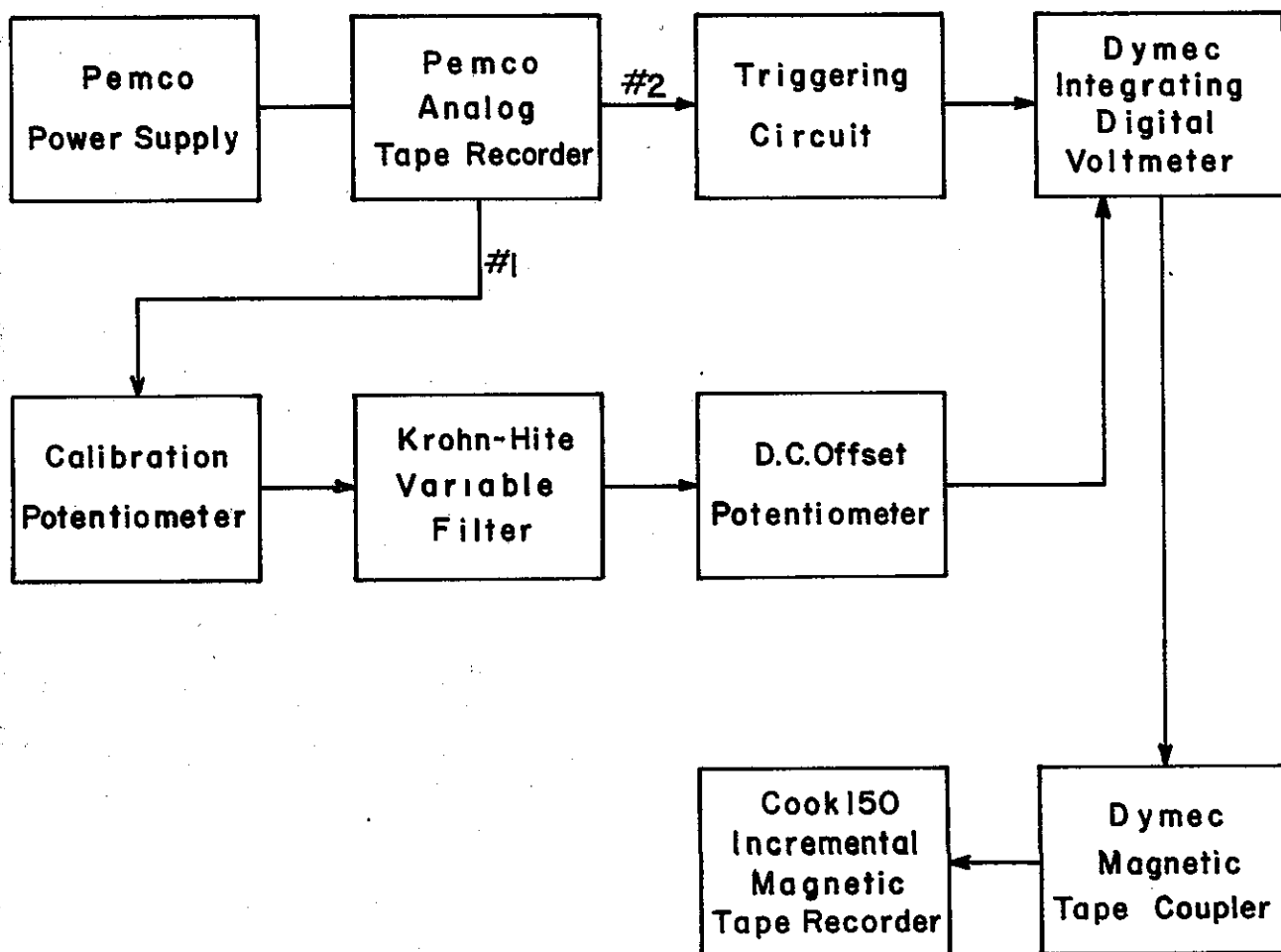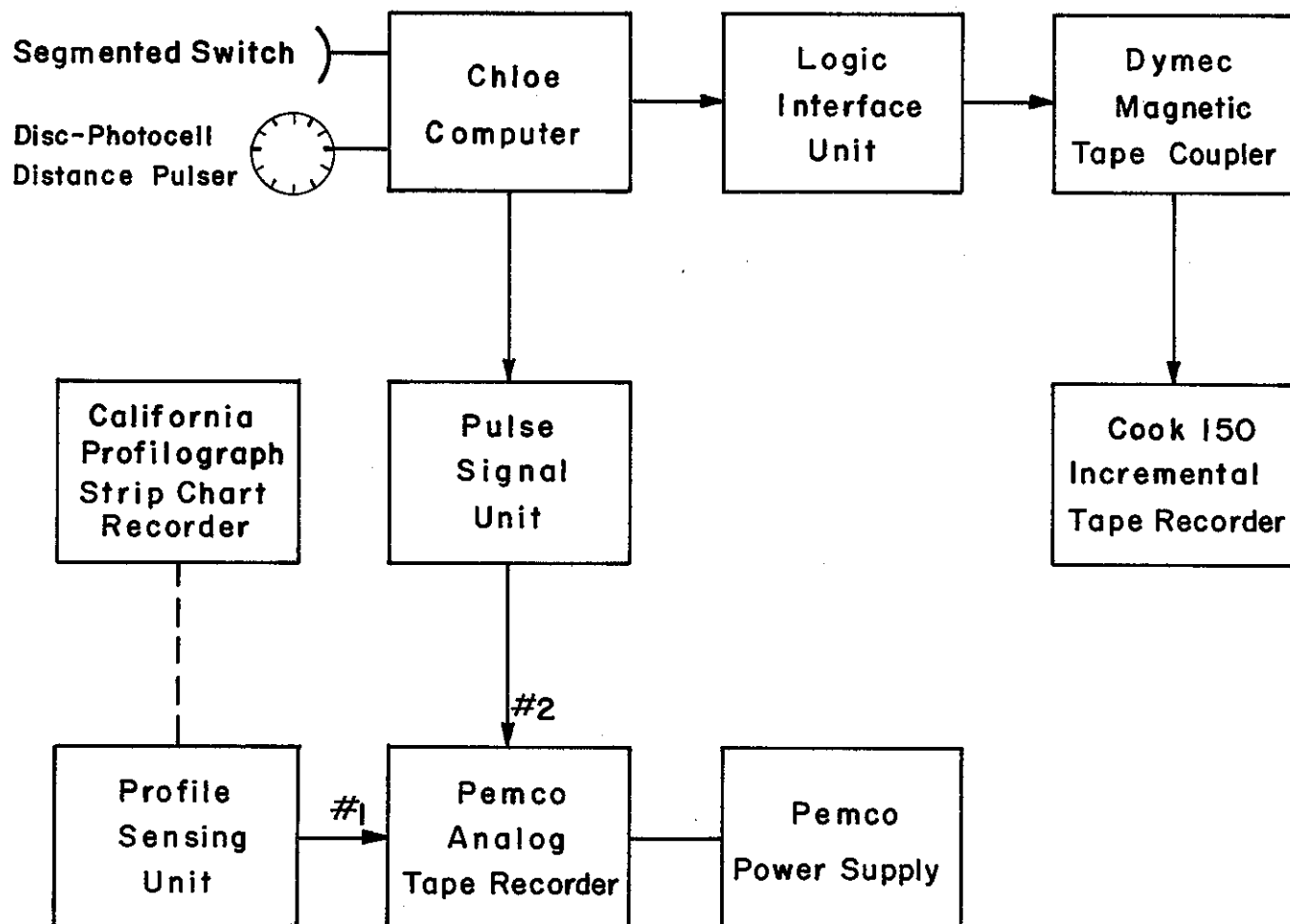
Figure 17

GENERAL DATA RECORDING SYSTEM

Block Diagram

A modification of the aforementioned program was written to enable us to handle the digitized profilograph data. Profile amplitude from a reference base line was recorded on the digital magnetic tape at intervals representing each 3 inches of travelled pavement. Approximately 4000 two-digit numbers constituted a file. This, again, represents approximately 1000 feet of pavement.

These 3-inch readings were used to develop a slope reading every 6 inches of travelled roadway using a 9-inch base as shown in Figure 18.
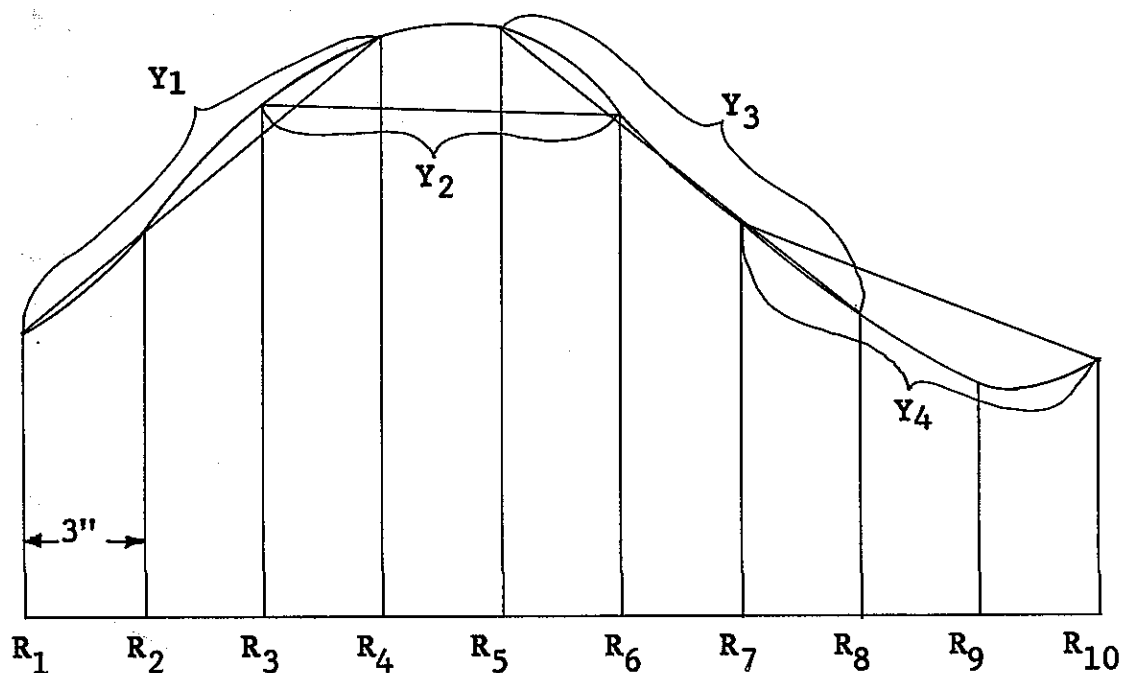

Figure 18

The following calculations were performed and the results printed out as in the original program:

$$Y_k = \overline{Y}_m + (R_{2i-1} - R_{2i+2})$$

Y_k = slope

$\overline{Y}_m$ = 13

R_j = amplitude reading

n = total number of two-digit numbers

i = goes from 1 to truncated $(\frac{n}{2} - 1)$

Let m = truncated $(\frac{n}{2} - 1)$

$$\text{Sumy} = \sum_{k=1}^{k=m} Y_k$$

$$\text{Sumyy} = \sum_{k=1}^{k=m} Y_k^2$$

Avg. = Sumy/m

$$\overline{SV} + 8.46 \left(\frac{\text{Sumyy}}{m} - \text{Avg.}^2\right)$$